1.0 INTRODUCTION

1.1 OVERVIEW

The East Bay Municipal Utility District (EBMUD) diverts water from the Mokelumne River pursuant to appropriative water rights issued by the State Water Resources Control Board (SWRCB). The District operates Pardee Reservoir and Camanche Reservoir on the Mokelumne River to provide water for municipal, irrigation, recreation, hydropower and fisheries uses, and to provide flood control protection.

The Woodbridge Irrigation District (WID) Dam blocked access for anadromous fish to the Mokelumne River from the late 1800s to the 1940s. The Lower Mokelumne River is defined as the stretch of the Mokelumne River that flows from Camanche Dam, at the western edge of the Sierra Nevada foothills, past the towns of Clements, Lockford, Victor, and Lodi and enters the Delta of the Sacramento and San Joaquin rivers (the Delta) near Thornton (Figure 1-1). The lower river supports many species of fish and wildlife and provides spawning and rearing habitat for salmon and steelhead trout.

In 1928, construction of Pardee Dam created an additional barrier for salmon and steelhead access to the Upper Mokelumne River (the stretch of the Mokelumne River between Pardee Dam and its headwaters), which may have included important summer habitat for steelhead trout. Completion of Camanche Dam in 1964 inundated 16 kilometers of salmon and steelhead habitat directly downstream from Pardee Dam. Mitigation for Camanche Dam was required for its approval by the U.S. Army Corp of Engineers (COE), the U.S. Fish and Wildlife Service (USFWS), the California Department of Fish and Game (CDFG), and the Federal Energy Regulation Commission.

EBMUD has operated under the same mitigation agreement with the CDFG since 1961. Mitigation included construction of the Mokelumne River Fish Hatchery (MRFH), reimbursement of CDFG direct operating and maintenance costs, and a reservation of 13,000 acre-feet of water stored in Camanche Reservoir to be used by CDFG for the benefit of the fishery. This water is in addition to other storage releases for downstream needs and water entitlements.

The California State legislature created the California Advisory Committee on Salmon and Steelhead Trout in 1983. This committee recommended doubling the populations of California salmon and steelhead by the year 2010. Much of the committee's work eventually became law. The State of California enacted a significant piece of legislation to address the decline of salmonid stocks called the *Salmon, Steelhead Trout and Anadromous Fisheries Program Act*. This Act has been incorporated into the CDFG code. Some of the Act's findings and declarations of CDFG include:

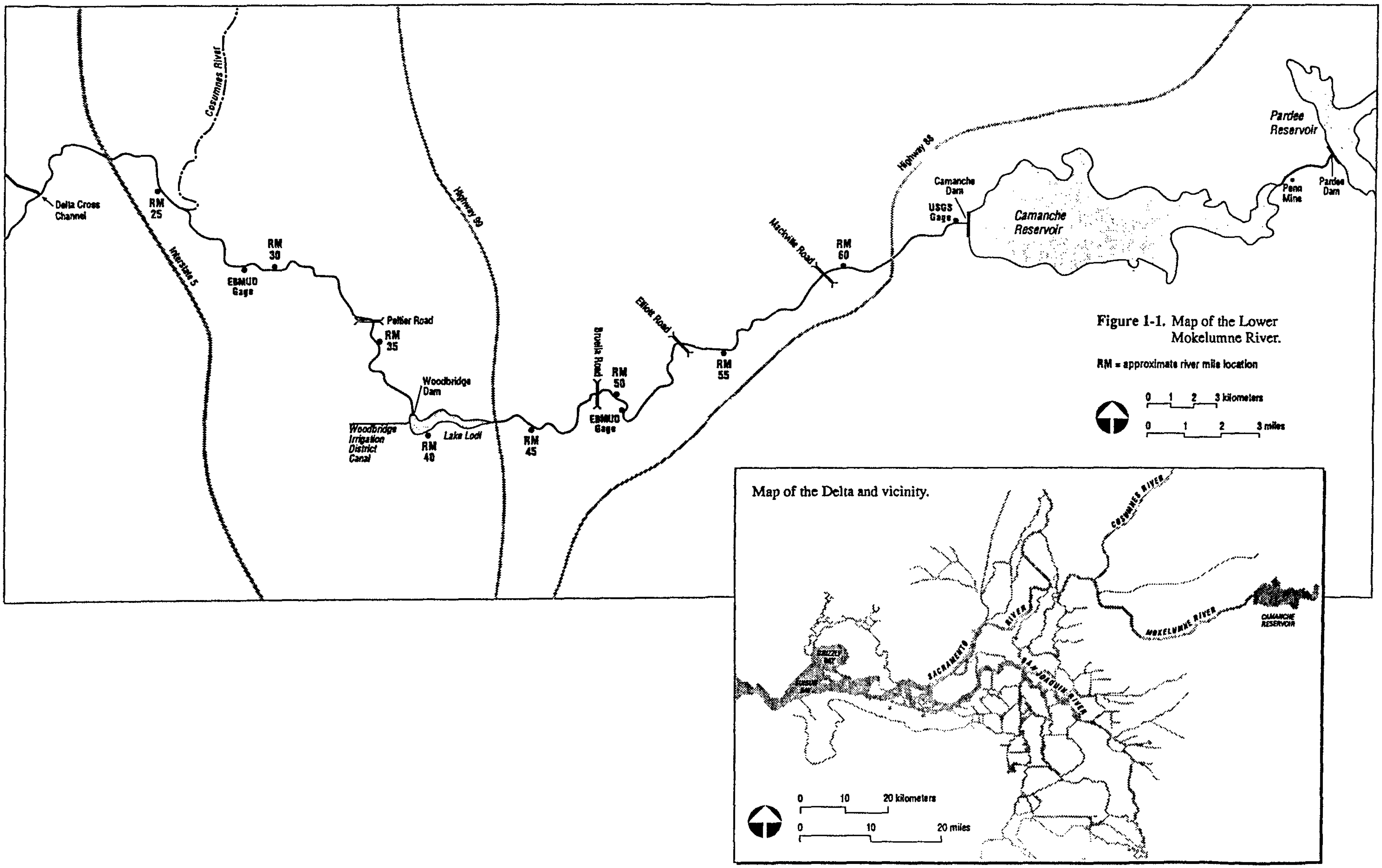

Figure 1-1. Map of the Lower Mokelumne River.

- The size of natural runs should be significantly increased.
- Public and private sector participation should be encouraged.
- No net decrease in natural habitat should occur.
- Protection of existing runs and mandated increases must come from stream habitat improvements and not the construction of new hatcheries.

The CDFG has recently addressed these issues for the Mokelumne River in their report entitled, *Lower Mokelumne River Fisheries Management Plan* (CDFG 1991). The CDFG report provides an assessment of instream flow and water quality needs for fish in the Lower Mokelumne River.

For several years, EBMUD has been involved in a planning process known as the Water Supply Management Program (WSMP). The Lower Mokelumne River Management Plan (LMRMP) is an element of the WSMP. The goal of the LMRMP is to establish a water management plan to sustain and restore the fishery of the Lower Mokelumne River while continuing to provide reliable water for use by EBMUD and other water users.

BioSystems Analysis, Inc. (BioSystems), under contract to EDAW, Inc., has prepared the *Lower Mokelumne River Management Plan.* The plan was developed for EBMUD to address the need for water for fisheries as part of the EBMUD WSMP Environmental Impact Statement/Environmental Impact Report planning process.

This plan incorporates the results of field studies conducted by the CDFG (1991) and takes into account recent field data and modeling studies conducted since the CDFG prepared its original draft plan. The BioSystems report presents an independent assessment of the Lower Mokelumne River fisheries and differs from the CDFG report in terms of stated fishery management goals, interpretations of data, and recommendations for achieving stated goals.

Many interests compete for water in the Lower Mokelumne River, and fisheries is only one component to consider in establishing future water allocations. The lower river is used for recreation, irrigation, and industrial purposes. Important irrigation diversions include the Woodbridge Irrigation District, the North San Joaquin Water Conservation District, and riparian users. Water is also "used" to maintain riparian vegetation and to recharge groundwater aquifers. Water releases from storage may also be required to meet Bay/Delta water quality standards. Figure 1-2 shows factors that affect EBMUD's need for water from the Mokelumne River.

It must be emphasized that, under state and federal law, some responsibility for managing fisheries in the Lower Mokelumne River is assigned to the CDFG, the National Oceanic and Atmospheric Administration (NOAA), and the USFWS.

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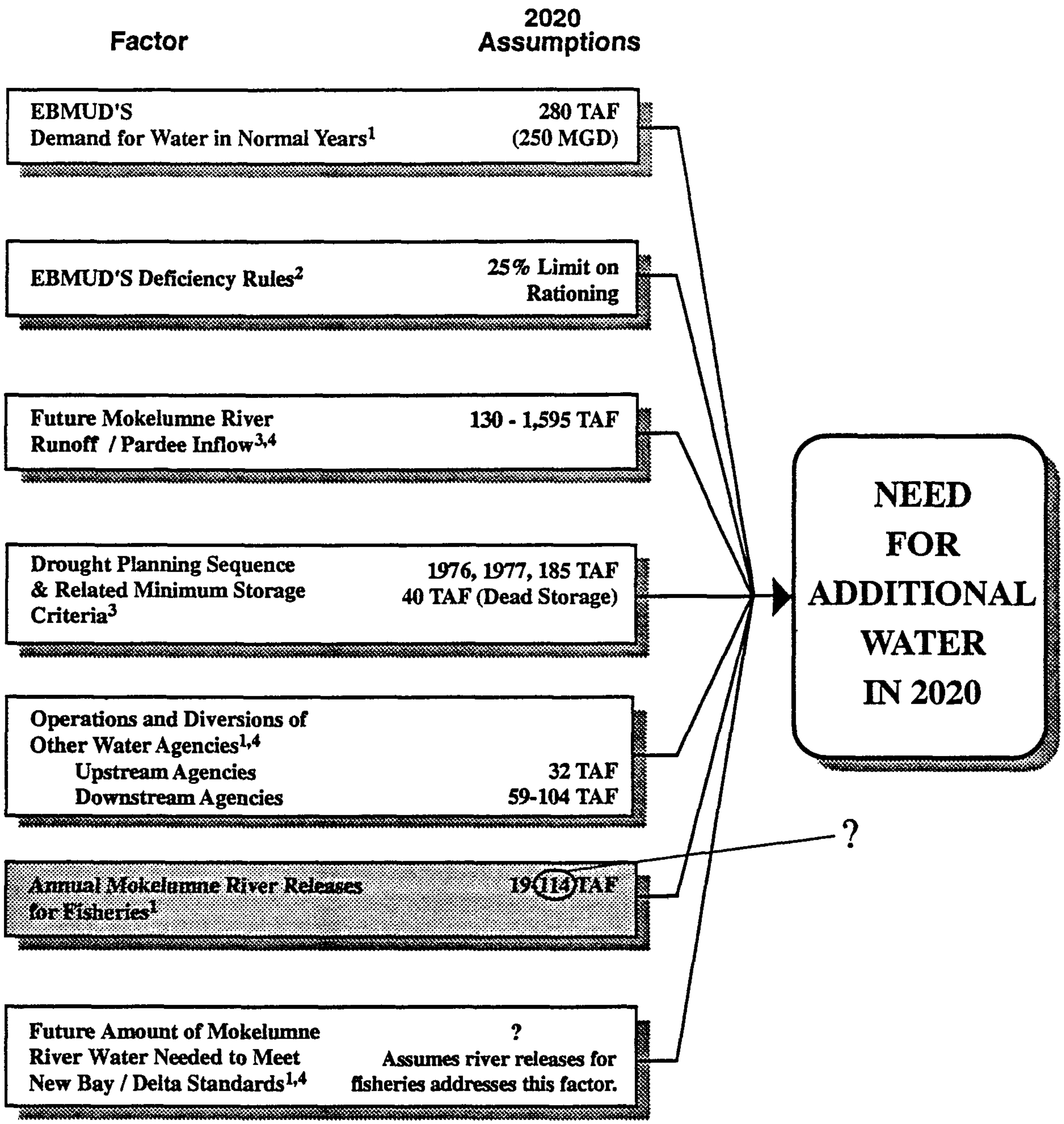

Notes:

1 Conditions adding to the District's need for water
2 Conditions reducing the District's need for water
3 Conditions which could add to or reduce the District's need for water
4 Conditions largely outside District's control

TAF = thousand acre-feet
MGD = million gallons per day
LMRMP = Lower Mokelumne River Management Plan

Source: EDAW Inc., and EBMUD

Figure 1-2. Key Factors Affecting the District's Need for Additional Water 08/25/92

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1.2 KEY BIOLOGICAL FACTORS AFFECTING THE MANAGEMENT OF THE MOKELUMNE RIVER FISHERY

The focus of fishery management on the Lower Mokelumne River has been and will continue to be the anadromous chinook salmon and steelhead trout populations (CDFG 1991). Anadromous fish are those that live in salt-water for a portion of their life but return to fresh-water to reproduce. Introduced striped bass may use the Mokelumne River below Woodbridge Dam in wet years, but there is no documentation to show they use this river section extensively. American shad, also an introduced species, have never been reported in large numbers in the Mokelumne River above the Delta. This species is more abundant in the Sacramento River and its tributaries. Native warm and coldwater fishes (other than chinook salmon and steelhead rainbow trout) are an important and apparently stable component of the aquatic community. Not much is known about their habitat requirements.

The population dynamics of the anadromous salmonid fisheries stocks of the Mokelumne River are similar to those in hundreds of other rivers that flow into the Pacific from California to Japan. Throughout the Pacific Basin, the size of anadromous fish stocks continues to decline in spite of the increase in scientific knowledge of the biology of these fish, curtailment of sport and commercial fishing activities, and the construction of modern hatcheries. In fact, nearly half of the 400 native, naturally-spawning stocks of salmon and trout in the Western states are extinct, and half of the remaining stocks are at high risk of extinction (Nehlsen et al. 1991). These declines have been caused by excessive commercial and recreational harvesting and the loss of freshwater habitat through construction of dams, pollution, and water diversions for agriculture, power generation, and other uses.

Chinook salmon in the Central Valley are differentiated into four races dependent upon the time of year in which adults migrate into fresh water to spawn. The races are fall run, late-fall run, winter run, and spring run. Historically, the spring run may have been the largest population of chinook salmon in the Sacramento-San Joaquin drainage (Moyle et al. 1989). During the past 150 years, spring-run populations throughout California's Central Valley have been reduced or eliminated due to historical mining practices, overfishing, and dam construction (Meyer 1982; Moyle 1976; Moyle et al. 1989).

Sexually mature fall-run chinook salmon move from the offshore Pacific waters into coastal estuaries, including San Francisco Bay, during the summer months. In the fall, the fish move upstream through the Delta to spawn. Historically, salmon returned to their natal stream, and natural stocks were genetically distinct. However, any distinctions between Central Valley stocks have been lost because of straying as a result of hatchery importation and exportation practices and flow alterations (see Section 3.2).

Salmon do not typically feed once they reach freshwater and, during the upstream migration, they become emaciated and weakened as their bodies undergo physiological changes. Once the spawning stream is reached, a female creates a depression in the gravel bottom by turning on her side and digging with her body and tail. One or more males fertilize the eggs as they are laid by the female. The female then moves slightly upstream and digs another depression; the gravel removed from the second excavation covers the eggs in the first nest. Eventually 4.6 square meters of streambed may be covered with her nests. Each depression, as well as the larger area containing many nests, is called a redd. After spawning, the adults die.

The eggs remain in the gravel for a few weeks to several months, depending on water temperature. Eventually, the fry emerge from the gravel and begin feeding on zooplankton and aquatic insects. By spring, fall-run chinook that were spawned in November and remained in the Mokelumne River are physiologically ready to live in salt water and begin to travel downstream toward the Delta on their way to the sea. These 5-10 centimeter long salmon are called smolts. However, some juveniles may migrate as fry in February and March and go through the smoltification process in the Delta. Some young salmon may remain in fresh water for a year before heading out to sea and are called yearlings. After about 1 to 2 years at sea, the males begin to mature sexually, and the cycle is repeated as the fish move into the estuaries. Females are usually not sexually mature until 2 to 3 years at sea.

The life cycle of steelhead trout is similar in many respects to that of chinook salmon, except that steelhead may remain in freshwater for 2 to 3 years after hatching. About the same length of time is then spent in the ocean. Unlike chinook salmon, some steelhead make the round trip to the ocean and back several times to spawn. Steelhead migrate into the river later than chinook (from November through February) and return to the ocean during the winter and early spring months, usually during the high flows that occur during storms.

1.3 HISTORICAL EVENTS AFFECTING FISHERIES RESOURCES

The Mokelumne River has a long history of water development. Present uses include hydroelectric power, irrigation, and municipal diversion facilities. Figure 1-1 shows the Mokelumne River, the surrounding watershed, and the San Francisco Bay/Delta region. Since the late 1800s, increasing demand for the river's resources for mining, agriculture, and water diversions has affected the river's fishery. Pollution from winery, cannery, and mining operations; construction of dams; and water diversions have resulted in loss of habitat, physical obstructions, and direct mortality. Chinook salmon and steelhead rainbow trout populations have been influenced by changes in water flows and temperatures during critical periods of migration, spawning, emergence, rearing, and out-migration. Fishery management practices, regulated by CDFG, USFWS, the National Marine Fisheries Service (NMFS), and others, including hatchery operations and ocean harvest management, have also affected these populations. As a result of these factors, spring-run chinook were eliminated from the river prior to the construction of Pardee Dam in 1929, steelhead trout populations are very low, and the native Mokelumne River run of fall-run chinook salmon has been replaced with a run consisting largely of stray fish from other rivers. Figure 1-3 is a time series summary of the major perturbations of the Mokelumne River.

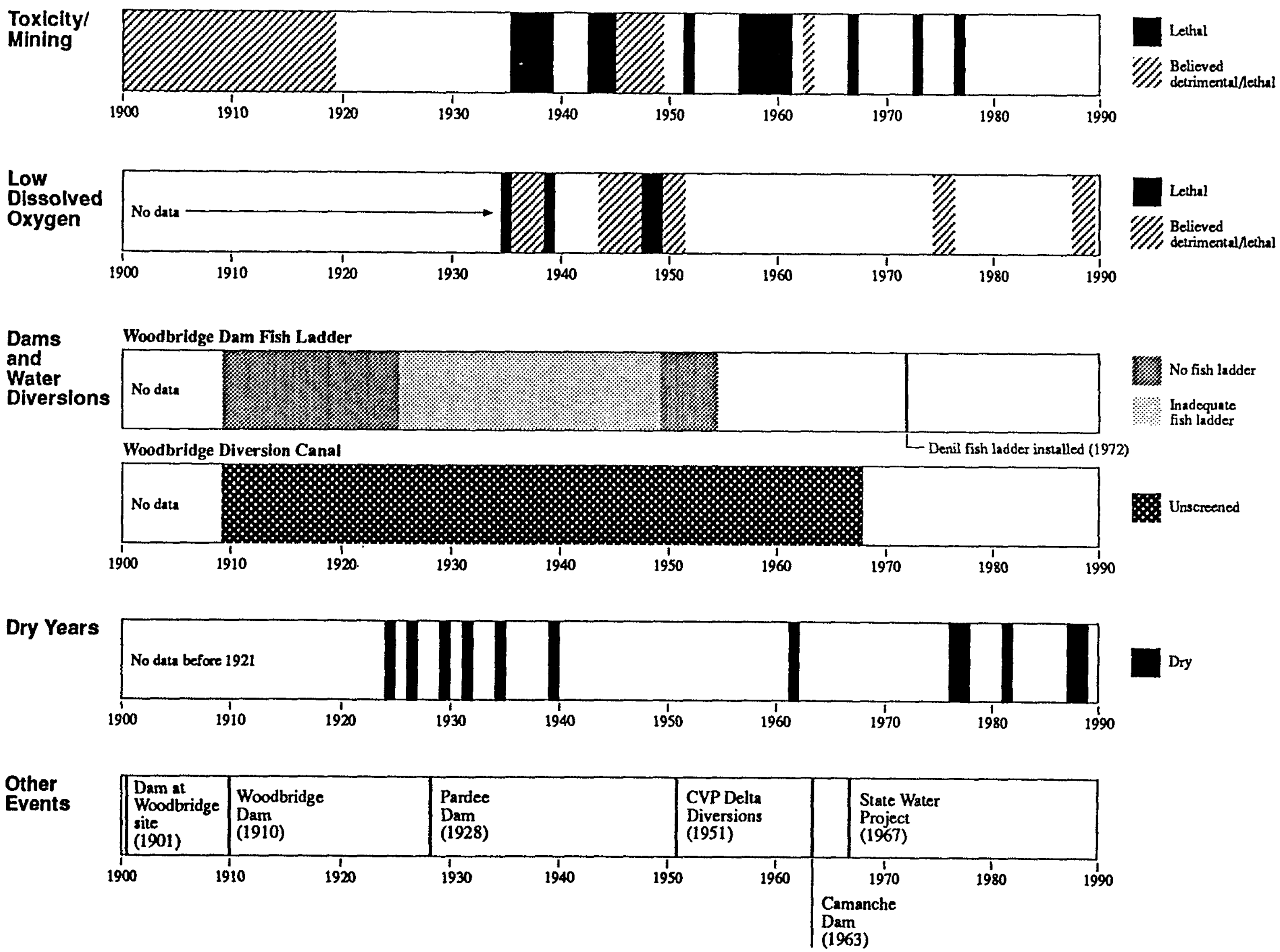

Figure 1-3. Summary of historical events affecting fishery resources of the Mokelumne River.

BioSystems

1.3.1 Mining

Degradation of the Mokelumne River increased dramatically with the discovery of gold in 1848. By 1850, so much water was diverted for gold mining that the riverbed was periodically left dry (Taylor 1850). Gold production peaked in 1854 and declined steadily until the turn of the century (Central Valley Regional Water Quality Control Board [CVRWQCB] 1952).

Copper was discovered in 1861 along the Mokelumne River at Penn Mine, 111 river kilometers upstream from the river mouth (Figure 1-1) and mined intensively between 1899 and 1919. Penn Mine closed in 1919 and, by 1926, the mine shafts were filled with water. Mining techniques and the lack of restrictions on waste disposal resulted in lethal heavy metal concentrations in the river (CDFG 1956). The discharge of water from Penn Mine caused many documented fish losses (Table 1.1).

In 1937, a shaft of Penn Mine was drained so that mining operations could be resumed and the water was discharged directly into the river. This coincided with the elimination of all aquatic life for 96 kilometers downstream (Shaw and Tower 1937; Finlayson and Rectenwald 1978). In 1943, Penn Mine was completely drained; the site was mined intensively through 1949 and periodically through 1956. Water was pumped from the mine directly into the river, from July through December 1943, at a rate of 950 liters per minute (CDFG 1956). Release of the mine effluent eliminated all downstream aquatic life, including salmon runs, from 1943 to 1944. Copper and zinc concentrations in the river were estimated at 200 times the chronic toxicity levels for fish (Paul 1952; Finlayson and Rectenwald 1978).

Other incidents of pollution occurred from 1943 to 1946 (CDFG 1956). A discharge in 1943 contained heavy metal sediments and in 1944 and 1946 pipes burst that carried slurry from the mine across the river to settling ponds. No estimates were made of the toxicity of the slurry water or its effects on fish life; however, fish did not return to the upper river until 1949.

In 1952, heavy metal concentrations in the river were near or exceeded lethal limits for fish, even though the mine was barely operational (Paul 1952). The mine was abandoned in 1956, and heavy-metal laden ore deposits and settling ponds were left along the riverbanks (Finlayson and Rectenwald 1978). These mine wastes continued to cause widespread fish losses downstream. Between 1957 and 1960, at least nine separate fish kills occurred along the Mokelumne River, apparently caused by heavy metal pollution (Finlayson and Rectenwald 1978).

During the fall of 1958, more salmon spawned in the river than at any other time between 1942 and 1983. However, in December and January of 1958 and 1959, heavy metal concentrations up to 300 times the lethal limits killed most of the eggs and fry in the river (Finlayson and Rectenwald 1978). During research on the feasibility of an artificial spawning channel on the Mokelumne River constructed at Lancha Plana, elevated copper and zinc concentrations in the river resulted in the loss of over 90 percent of the adult salmon

Table 1.1. Documented fish losses on the Mokelumne River between 1937 and 1989.

YEAR	LOCATION	FISH	NUMBER	ASSOCIATED CONDITIONS	REFERENCES
1937	Downstream from Lodi wineries	Salmon	NA	Low oxygen from winery waste	CDFG 1937
1937	Penn Mine to Delta	All	All	Heavy metals	Shaw and Towers 1937
1939	Downstream from Lodi wineries	Salmon	>100	Heavy metals	Hatton 1940
1943-1945	Penn Mine to Delta	All	All	Heavy metals	Paul 1952; EBMUD 1990
1948	Downstream from Thornton Cannery	NA	NA	Low oxygen from cannery waste	CVRWPCB 1952; EBMUD 1990
1957	20 km downstream from the Penn Mine	Steelhead	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1958	20 km downstream from the Penn Mine	Sculpins, suckers, lampreys	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1958	15 km downstream from the Penn Mine	Steelhead, suckers, lampreys	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1959	Camanche Bridge	Salmon, steelhead sculpins, bullhead, lamprey, suckers	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1959	15 km downstream from the Penn Mine	Salmon, steelhead, sculpins, suckers	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1959	Camanche Bridge	Salmon, sculpin	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1959	Camanche Bridge	Salmon	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1960	Lancha Plana	Steelhead, suckers	NA	Heavy metals	Dunham 1961; Finlayson and Rectenwald 1978
1960	Lancha Plana	Salmon adults	95%	Heavy metals	Menchen 1961
1961	Lancha Plana	Salmon fry	99%	Heavy metals	Menchen 1961
1967	MRFH	Salmon fry	1,900	Heavy metals	Jewett 1971; Finlayson and Rectenwald 1978
		Steelhead	17,600		
1973	MRFH	Steelhead	46,200	Heavy metals	Jewett 1974; Finlayson and Rectenwald 1978
1977	MRFH	Steelhead	28,373	Heavy metals and hydrogen sulfide	Jewett 1980
		Salmon fry	>100,000		

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Table 1.1. Documented fish losses on the Mokelumne River between 1937 and 1989 (cont.).

YEAR	LOCATION	FISH	NUMBER	ASSOCIATED CONDITIONS	REFERENCES
1987	MRFH	Steelhead	109,000	Hydrogen sulfide and elevated temperature	Estey 1989; Horne 1989; EBMUD 1990
1988	MRFH	Steelhead Salmon	>45,000 28,000	Hydrogen sulfide and low oxygen	Estey 1990; EBMUD 1990
1989	MRFH	Steelhead	153,000	Hydrogen sulfide	Miyamoto 1989; EBMUD 1990

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and fry being monitored (Menchen 1961). Although water samples were not taken continuously throughout the experiment, copper and zinc concentrations were as high as 14 times the lethal level (Menchen 1961).

Even after Penn Mine had been closed for more than 10 years, heavy metals from the mine continued to cause fish losses. Rain flooded the settling ponds at Penn Mine several times, and large water releases were made from Pardee Dam which transported metal-laden sediments downstream. These events resulted in the loss of fish at the MRFH in 1967, 1973, and 1977 (Finlayson and Rectenwald 1978).

At the time, it was thought that since "the decline of the king salmon and steelhead resources . . . are primarily the result of copper and zinc toxicity from Penn Mine," re-establishment of these populations would occur when this problem was eliminated (Finlayson and Rectenwald 1978). In 1979, EBMUD, the SWRCB, and CDFG combined resources and constructed a dam below the settling ponds to contain drainage and reduce the amount of heavy metals discharged into Camanche Reservoir. Since construction of this dam, the annual surface flow from Penn Mine drainage into the Mokelumne River via Mine Run Creek has decreased by over 90 percent (SWRCB 1991).

1.3.2 Industrial Development

Wineries around Woodbridge Dam began discharging organic waste into the Lower Mokelumne River in about 1933. Organic waste harms aquatic life because it depletes oxygen as it decomposes. By 1935, 1,862,000 liters of winery waste a day were being dumped into the river (San Joaquin County Health District [SJCHD] 1935). In 1937, dissolved oxygen levels in the river fell below that needed to support fish life; this resulted in fish losses below the winery outfalls and a blockage of upstream migration (CDFG 1937). In 1939, low levels of dissolved oxygen again resulted in the loss of several hundred salmon and blocked upstream migration (Hatton 1940). As a result, the State Public Health Department enforced the pollution laws and, within two weeks, oxygen levels increased and the upstream migration began (CDFG 1956).

Most of the wineries were closed between 1940 and 1943. Dissolved oxygen levels in the river returned to normal and large salmon migrations resumed. The wineries again began releasing effluent directly into the river in 1943 and by 1945 the salmon runs had virtually disappeared (CDFG 1956).

Canneries also discharged organic waste into the river. In 1948, discharge from Thornton Cannery in Thornton reduced dissolved oxygen levels in the river to almost zero. Oxygen depletion resulted in fish losses downstream from the cannery and blocked upstream migration. The cannery was ordered to cease discharge immediately or face legal action by the state. From 1948 through 1952, low dissolved oxygen levels were periodically measured during the canning season. However, salmon stocks were unaffected since the canning season was usually over by the middle of October (CDFG 1956). By 1952, both winery and cannery discharges were being treated to comply with state regulations and fish life was no longer threatened (CVRWQCB 1952).

1.3.3 Dams

Construction of dams along the Mokelumne River has hindered salmon migration since at least 1891 when a dam was constructed near the present site of Woodbridge Dam near Lodi, 57 kilometers upstream from the river mouth. The dam failed in 1895 and was replaced with a wooden dam in 1901. In 1910, the wooden dam was replaced by Woodbridge Dam, a 50-meter wide flashboard dam that is in place from April through October during the irrigation season. The dam had no fish ladder until 1925. Each fall after the irrigation season (usually October or November), the flashboards are removed, and the 2,000 acre-foot impoundment (Lake Lodi) is drained. During March or April of each spring, the boards are placed in the dam frame, Lake Lodi fills, and the water is diverted into the WID Canal intake.

Construction of Woodbridge Dam blocked access to all salmon and steelhead spawning habitat during the irrigation season from 1910 until 1925 when a fish ladder was built. This structure would have had a major impact on spring-run salmon since they migrate upstream between March and May. The fish ladder, constructed in 1925, was small and there was little, if any, flow through the ladder during the fall (Clark 1929). This inadequate fish ladder was replaced 23 years later in 1948 with a more effective structure. The new ladder washed out during a flood in 1950 when flows were over 25,000 cubic feet per second (cfs), the highest ever recorded on the Mokelumne River (USGS 1989).

A new fish ladder was built over Woodbridge Dam in 1955 and the CDFG stated that with the new ladder salmon stocks should return to historical levels (Lodi-News Sentinel, 17 November 1955). Today, there are two fishways for chinook salmon at Woodbridge Dam: one for passage when the lake is drained and one for passage when the lake is full. An additional Denil fishway was installed in 1972 to aid steelhead trout passage. Although numerous improvements to the present system have been suggested, there is no documentation that the present configuration of the dam or its fishways block salmon and steelhead migration.

In 1928, Pardee Dam was constructed upstream from Woodbridge Dam approximately 117 river kilometers upstream from the river mouth. This concrete dam is 105 meters high and stores 209,950 acre-feet of water. Pardee Reservoir has 59 kilometers of shoreline and a maximum surface area of 913 hectares. Flow releases from Pardee Dam provide for incidental electric power generation. The Pardee Power Plant has a maximum capacity of 27 megawatts.

Spring-run chinook salmon were eliminated from the Mokelumne River prior to 1929 (Clark, 1929), and the lack of a fish ladder at Woodbridge Dam, construction of Pardee and Camanche dams, mining operations, overfishing, poaching, and unscreened diversions all affected the fall-run chinook salmon and steelhead trout populations.

In 1962, construction began on Camanche Dam located 16 kilometers below Pardee Dam, and 103 kilometers upstream from the mouth of the Mokelumne River. The 72 meter high dam, completed in 1964, was built for flood control and stream-flow regulation and storage. Camanche Reservoir can hold 430,880 acre-feet of water and, at maximum capacity, has a surface area of 18,833 hectares. The reservoir has 101 kilometers of shoreline and a maximum depth of 41 meters. The construction of Camanche Dam inundated 80 percent of the remaining fall-run salmon spawning habitat as well as most of the steelhead trout habitat on the Mokelumne River (CDFG 1955; Fry and Petrovich 1970). The remaining spawning habitat now extends for about 11 kilometers downstream from the base of Camanche Dam to below Mackville Road Bridge.

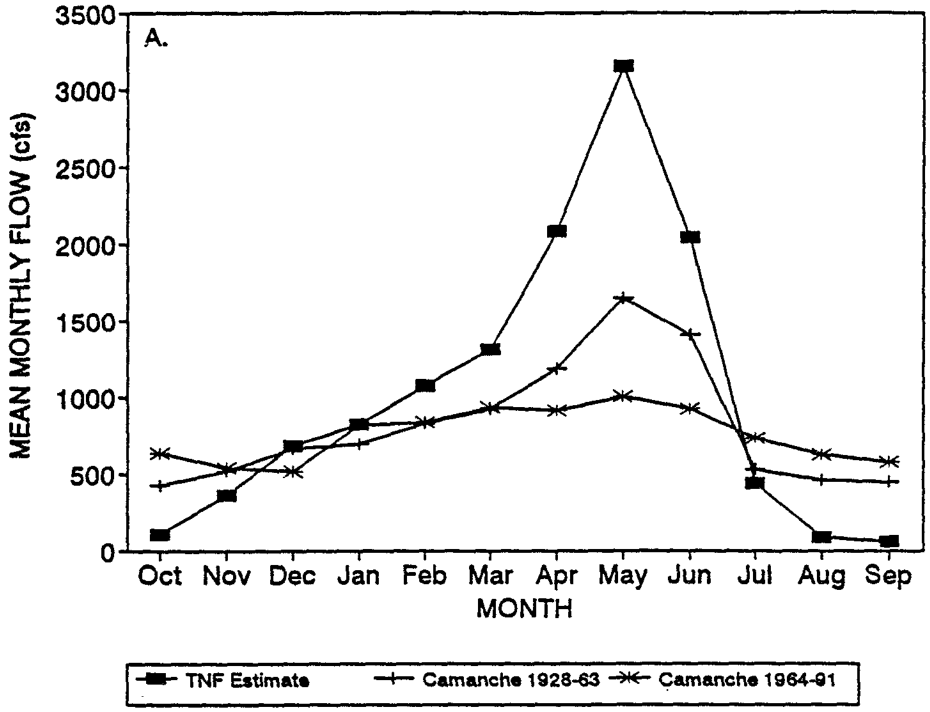
1.3.4 Flow Modifications

The Mokelumne River watershed drains a region of the central Sierra Nevada from the Sierra crest to the foothills in central California. River flows on the lower river are recorded at gaging stations maintained by the United States Geological Service (USGS) at Mokelumne Hill, below Camanche Dam, and below Woodbridge Dam. EBMUD also generates an estimate of unimpaired flow called "true natural flow" (TNF) into Pardee Reservoir. This estimate is based on measured riverflow but is corrected for the upstream project operations of Pacific Gas and Electric Company (PG&E) and other water users. This estimate does not account for downstream storage and diversion and is intended as an estimate of historical flow conditions prior to the construction of any water storage and diversion facilities.

From 1928 to 1988, mean monthly TNF estimates peaked in May at approximately 3,200 cfs and fell to 100 cfs in September and October (Figure 1-4). High flows from March to July are caused by spring snow melt runoff. Average unimpaired runoff in the Lower Mokelumne River is over 1,000 cfs.

Pardee and Camanche reservoirs have a combined storage capacity of over 641,000 acre-feet of water. This is equivalent to almost 90 percent of the mean annual runoff of the entire Mokelumne River Watershed Basin.

The purpose of the Pardee project was to store the high spring flows and divert a portion of them out of the basin to the East Bay. As a result of the Pardee project, river flows from July through November were increased over historical unimpaired river flows. The operation of Camanche Dam (beginning in 1964) resulted in further reductions in spring flows and a slight additional increase in summer and fall flows below Camanche Dam (Figure 1-4). These hydrologic modifications improved naturally existing habitat for the fall-run salmon and winter-run steelhead populations. Historically, unimpaired flow estimates and measured flows (at Camanche and Woodbridge dams) have differed considerably within and between years because of differences in water availability (precipitation, snowmelt, and release schedules). The historic variability in monthly flow was analyzed using exceedance analysis (Figure 1-5). Low flow was defined to occur during the 10 percent of the period of record when monthly flows were the lowest. Because low flow is exceeded 90 percent of the time, it is also referred to as the 90 percent exceedance flow. Normal flow is exceeded



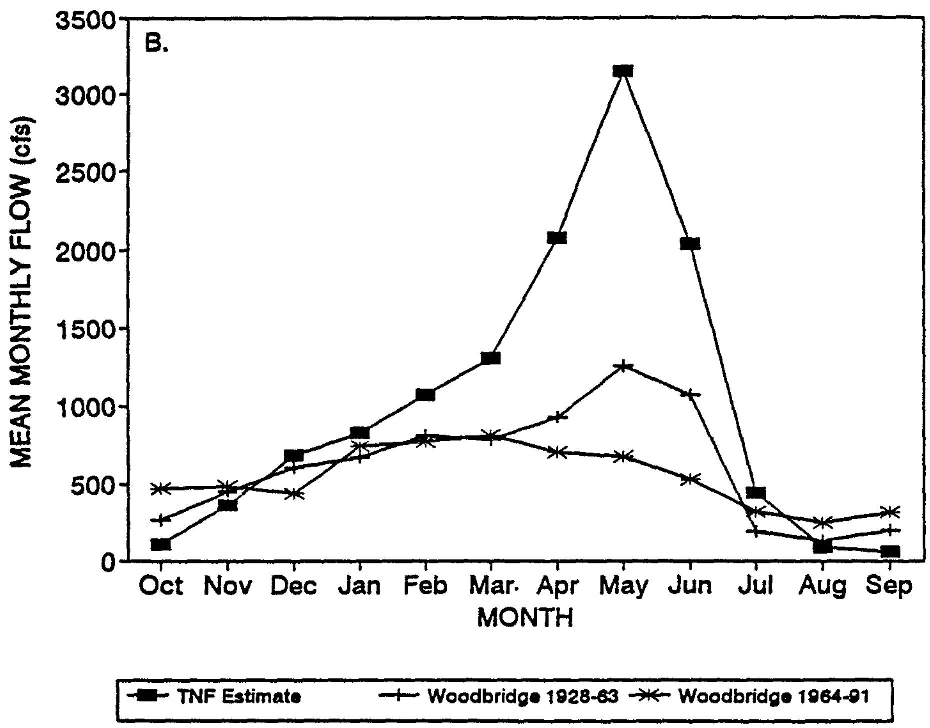


Figure 1-4. Mean monthly flow in the Mokelumne River at two sites before and after the construction of Camanche Dam: A) Camanche Dam (USGS gage 11323500, 1928-1991) and B) Woodbridge Dam (USGS gage 11323550, 1928-1991). Includes the mean true natural flow (TNF) estimates at Mokelumne Hill (1928-1988).

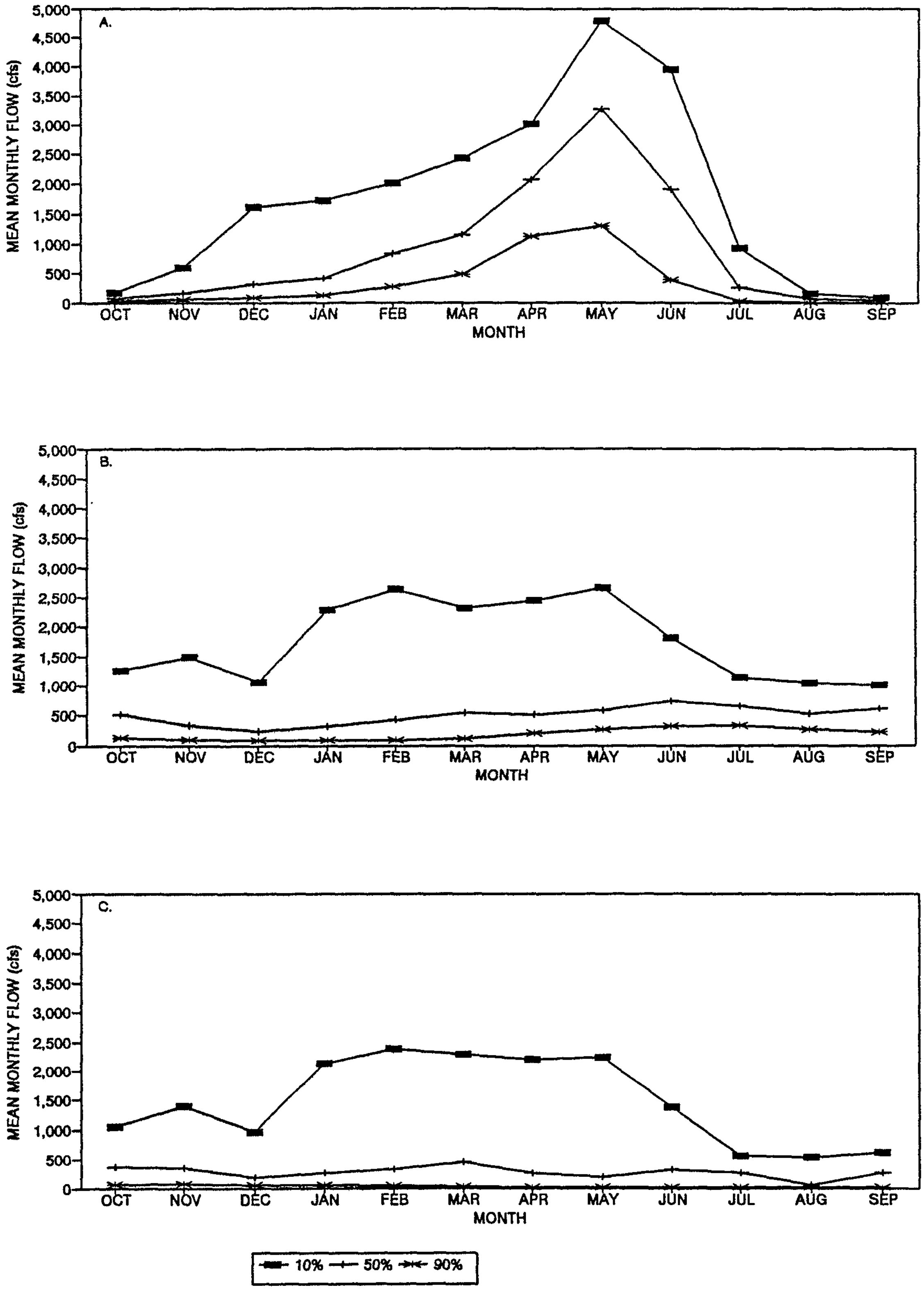


Figure 1-5. Exceedance flows (10%, 50%, and 90%) in the Mokelumne River based on A) monthly TNF estimates at Mokelumne Hill (1928-1988) and mean monthly flow at B) Camanche Dam (1965-1991) and C) Woodbridge Dam (1965-1991).

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50 percent of the time (50% exceedance), and high flow is only exceeded 10 percent of the time (10% exceedance). The mean monthly flow during each year was ranked by volume to assess the relative magnitude of high, normal, and low flows for each month of the year.

Based on TNF estimates (1928-1988), normal flow (50% exceedance) into Pardee Reservoir increases from about 40 cfs in September to 3,300 cfs in May with the greatest increase during the spring (Figure 1-5). During the summer, flow decreases sharply from about 1900 cfs in June to 60 cfs in August. In high and low flow periods, the peak flow is also in May and the lowest flow is in September; however, the magnitude of these flows are quite different. During high flow periods (10% exceedance), flow ranges from about 100 cfs in September to 4,800 cfs in May and decreases sharply during the summer (3,900 cfs in June to 160 cfs in August). The 90 percent exceedance flow (low flow) increases gradually from 4 cfs in September to only 1,300 cfs in May, before decreasing to almost zero during the summer (3 cfs in August).

Since the completion of Camanche Dam, downstream flow has remained relatively constant throughout the year compared to the TNF estimates (Figure 1-5). Based on flow at Camanche Dam, the 50 percent exceedance flow peaks at about 700 cfs during the height of the irrigation season (June) and declines to between 200-300 cfs during the winter. The 10 percent exceedance flow (high flow) ranges between 1,000 cfs (September) and 2,700 cfs (May) throughout the year, with flow above 2,000 cfs from January through May. The 90 percent exceedance flow (low flow) only ranges between about 100 and 300 cfs throughout the year; the highest flows occur from May through August because of downstream water deliveries to the WID (Figure 1-5).

Seasonal flow patterns below Woodbridge Dam are similar to flow patterns below Camanche Dam, except that flow below Woodbridge Dam is reduced between March and October because of diversions into the WID Canal (Figure 1-5). During low flow years, there is very little flow in the river below Woodbridge Dam. To maintain positive flow at the mouth of the river, EBMUD releases water from Camanche Dam to obtain approximately 25 cfs below Woodbridge Dam in low flow years.

1.3.5 Water Diversion

The earliest diversions of Mokelumne River water were for mining activities in the Mokelumne River canyon. These operations resulted in periodic but complete diversion of the Mokelumne River, until gold production began declining around 1854. In 1865, the Mokelumne River Improvement Company was formed to ensure river flow and to maintain a stream channel because of problems caused by diversions (Mokelumne River Improvement Company 1865).

Water diversion for mining has declined substantially during the last century, but diversion for irrigation has increased. The first diversion of Mokelumne River water for irrigation occurred before 1890 (CVRWQCB 1952). The principle means of diverting water for irrigation are the WID Canal, the North San Joaquin Water Conservation District pumps, and riparian irrigators. Annual diversion rates for the WID Canal and total pump diversions between 1953 and 1990 are included in Table 1.2 and Figure 1-6.

Thirty-nine kilometers of the WID Canal were built in 1895 when the first Woodbridge Dam was constructed. Currently, the canal has a maximum capacity of 415 cfs and usually operates from March through October; the actual dates vary depending on irrigation water needs. Flow in the canal is controlled by altering the height of the flashboards to raise or lower the level of Lake Lodi.

The WID Canal was constructed with no means of preventing salmon fry or smolts or steelhead juveniles from entering the canal during operation. As early as 1940, it was obvious that "first and foremost among the desired improvements (to salmon stocks) are adequate fish screens on the irrigation diversions throughout the San Joaquin River system" (Hatton 1940). "For decades, the lack of a fish screen on the Woodbridge Irrigation Diversion Canal has been a major block to the rehabilitation of Mokelumne River salmon runs" (Fry and Petrovich 1970).

After 58 years, a screen was built by CDFG across the WID Canal in 1968 to prevent further loss of out-migrating salmon and steelhead. While this screen significantly reduced the loss of salmon smolts, potential problems remain with entrainment and operation of the fish screens and bypass pipelines. Fisher (1976) reported that the mesh size of the screen at the WID Canal was inadequate to prevent out-migrating salmon smaller than 40 millimeters fork length from passing through the screen into the WID Canal (Vogel 1992).

Diversion rates in the WID Canal have varied with water availability and irrigation demands. Limitations to WID's water entitlement reduce its allotment in dry years. However, irrigation demand is a larger proportion of river flows in years with low rainfall when total runoff and river flow are also low. In many years, most of the river flow is diverted into the canal during late spring and early summer (May-July) when most (95%) salmon smolts are migrating out of the river (Figure 1-7).

Juvenile salmon migrate out of the river as fry during February and March and as smolts during April through June. Large water diversions for irrigation (after March) can significantly reduce river flows during the out-migration period. Schaffter (1980) proposed that the proportion of loss of out-migrants (number diverted into the canal) was equal to the proportion of water diverted. Based on Woodbridge diversion rates, it appears that, in many years prior to the construction of the fish screen, most salmon and steelhead migrating out of the Mokelumne River were lost into the canal.

Diversion of water into the WID Canal from the Mokelumne River reduces flows below Woodbridge Dam. This affects the ability of salmon smolts to migrate out through the lower river and into the Delta and results in longer out-migration time, higher temperatures (Meyer 1984), and higher mortality. Lake Lodi is used to facilitate diversion during the irrigation season. Smolts entering the lake face irrigation delays and increased predation.

Table 1.2. Summary of diversions from the Mokelumne River, including the WID Canal and riparian pumps, 1953-1990. Based on annual USGS reports (1953-1990) and EBMUD pump data (1965-1990). Pump data unavailable 1963-1965.

WATER YEAR	TOTAL DIVERSION (acre-feet)	WID CANAL (acre-feet)	PUMPS (acre-feet)	PUMPS NUMBER
1953	164,080	148,290	15,790	65
1954	155,631	133,200	22,431	67
1955	118,386	97,080	21,306	76
1956	142,853	127,800	15,053	70
1957	124,450	107,000	17,450	72
1958	122,500	107,900	14,600	64
1959	126,180	103,400	22,780	72
1960	127,100	100,900	26,200	72
1961	83,880	63,020	20,860	69
1962	137,060	115,120	21,940	69
1963	unknown	103,200	unknown	-
1964	unknown	74,310	unknown	-
1965	unknown	88,030	unknown	-
1966	137,210	108,800	28,410	92
1967	125,020	100,300	24,720	90
1968	142,459	110,600	31,859	93
1969	136,119	108,600	27,519	84
1970	151,296	119,700	31,596	92
1971	150,842	121,700	29,142	91
1972	143,572	109,300	34,272	84
1973	137,580	108,700	28,880	83
1974	133,154	103,800	29,354	86
1975	128,999	99,470	29,529	82
1976	85,301	72,320	12,981	85
1977	72,745	51,440	21,305	85
1978	80,670	61,460	19,210	89
1979	101,242	76,220	25,022	87
1980	98,843	73,700	25,143	86
1981	107,162	80,690	26,472	87
1982	83,370	69,790	13,580	85
1983	77,269	59,170	18,099	59
1984	114,819	89,800	25,019	78
1985	99,510	77,480	22,030	82
1986	81,366	61,260	20,106	75
1987	93,290	72,830	20,460	80
1988	75,505	56,230	19,275	77
1989	74,784	55,380	19,404	73
1990	67,959	54,980	12,979	71
Mean 1953-1990	114,349	91,394	22,708	79

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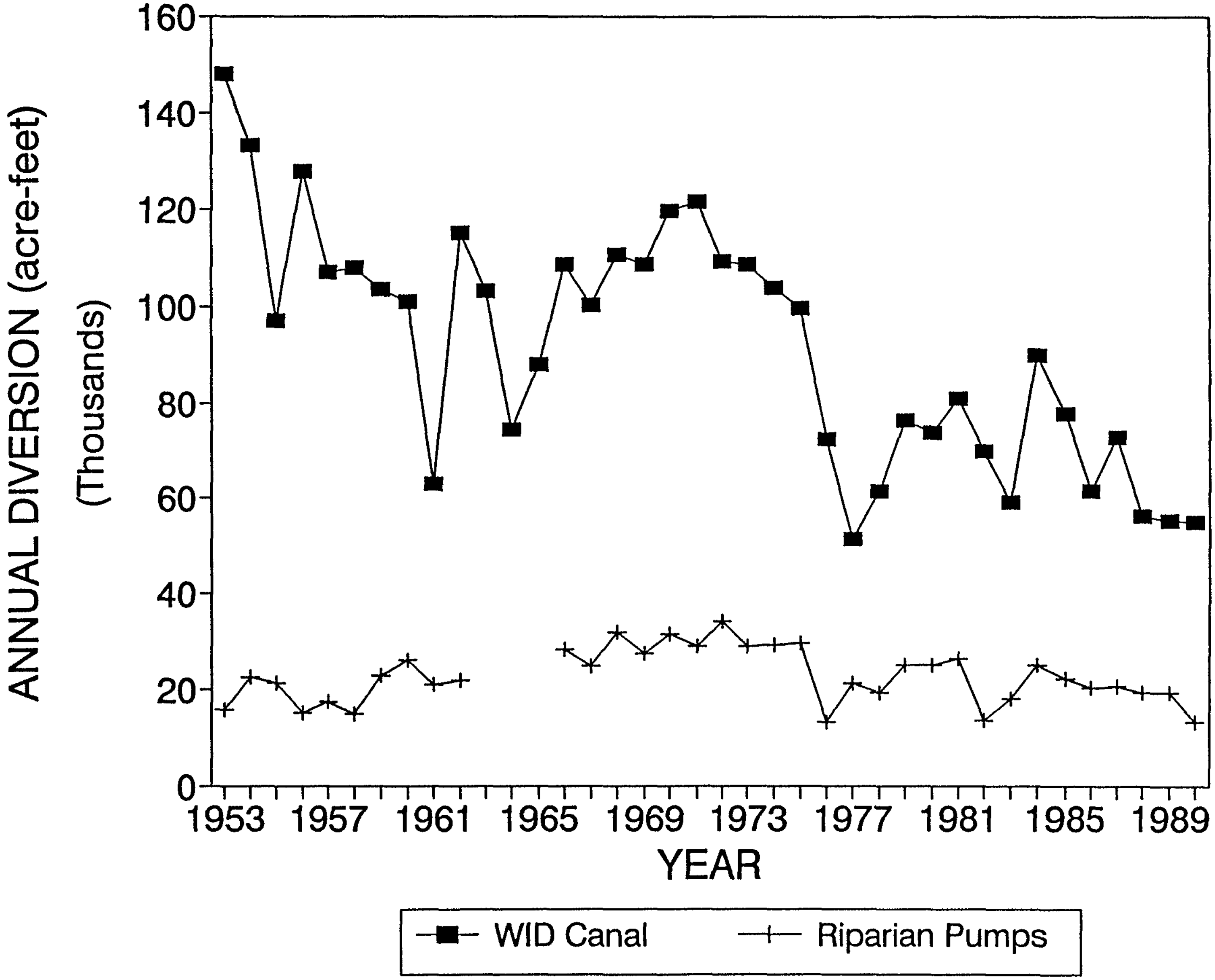

Figure 1-6. Mokelumne River irrigation diversions, 1953-1990. Riparian pump data unavailable for 1963-1965.

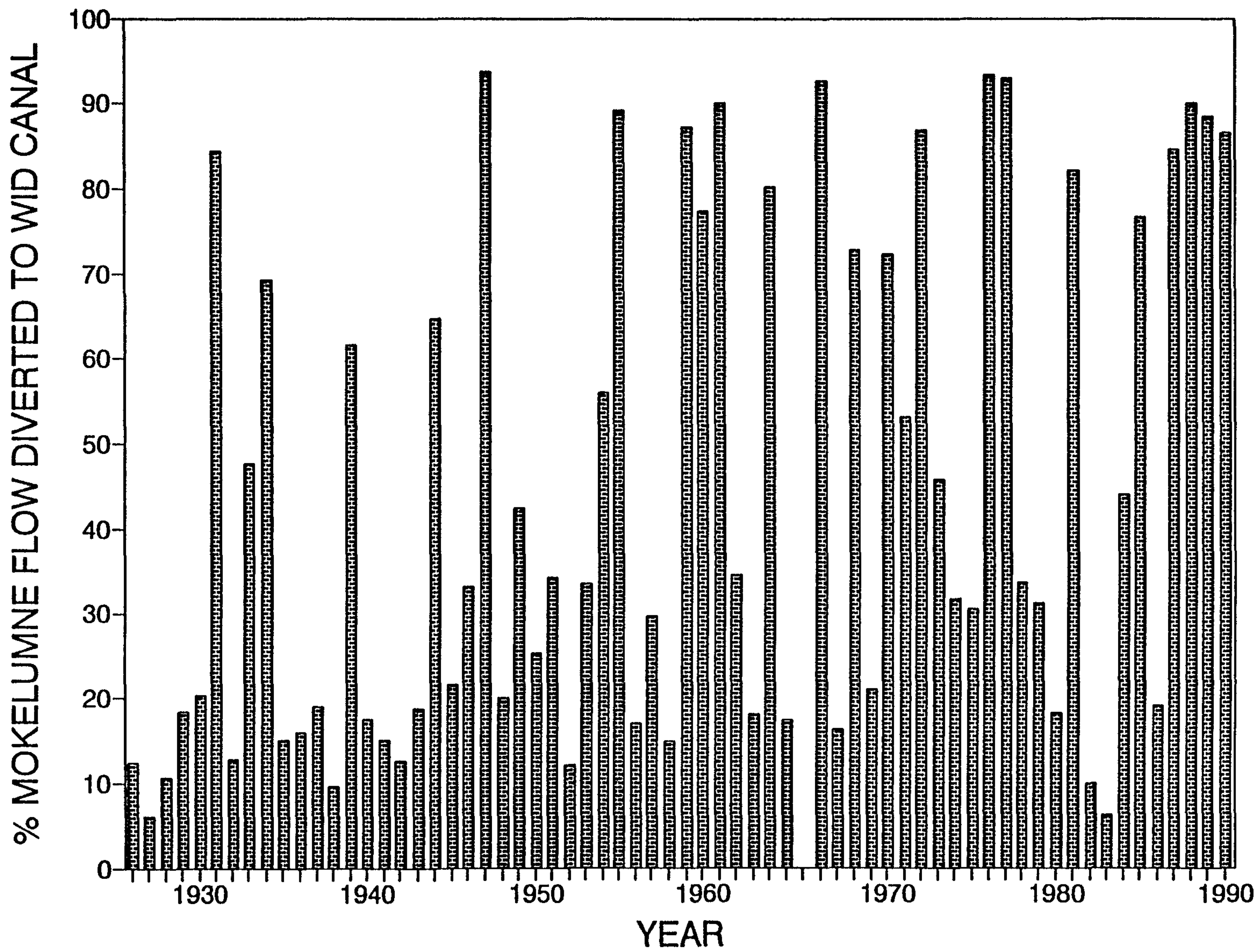

Figure 1-7. Mean diversion rates into the WID Canal, May through July, 1926-1990. Based on USGS flow data below Woodbridge Dam (gage #11323550) and in the WID Canal (gage #11325000).

Most irrigation diversions (WID Canal, North San Joaquin Water Conservation District, and riparian pumps) occur during the agricultural growing season between April and September (Figure 1-8). Studies of salmon smolts in the Mokelumne River show that the peak of the out-migration occurs in May and June (Table 1.3). Since pumps have been used on the Mokelumne River since the 1890s (USGS 1926), salmon and steelhead populations have been affected by irrigation diversion for a century. By 1928, approximately 60 pumps were diverting a total of about 4,000 acre-feet of water from the river during the irrigation season (USGS 1929). In 1950, 66 pumps were drawing approximately 15,000 acre-feet of water from the river between Thornton and the Highway 88 Bridge near Clements (a span of approximately 64 km). The use of pumps for farming and ranching climbed steadily until it peaked in 1972 when over 34,000 acre-feet was diverted from the river by 91 pumps (EBMUD data files Lodi, California). Since 1972, the number of pumps in operation has decreased, as well as the amount of water diverted.

Table 1.3. Summary of the salmon smolts trapped at Woodbridge Dam.

YEAR	SALMON TRAPPED	ESTIMATED SPAWNING STOCK	PEAK CATCH (week)	PERIOD OF OPERATION
1967-68	106,105	3,000	4th wk. of May	4 May-28 June
1969-70	25,489	3,000	4th wk. of May	6 April-15 June
1970-71	9,235	5,000	4th wk. of May	22 May-26 July
1971-72	51,579	5,000	1st wk. of June	22 March-5 July
1972-73	305	1,100	NA	18 June-9 July
1975-76	175,377	1,900	4th wk. of May	18 March-16 July
1976-77	51,638	500	3rd wk. of May	23 March-11 July
1980-81	73,121	3,200	4th wk. of May	13 April-29 June
1984-85	112,122	5,969	4th wk. of May	3 May-15 August
1986-87	53,306	5,000	NA	6 April-23 June
1987-88	22,124	1,630	NA	11 April-20 June
1988-89	81,325	186	NA	18 April-19 June
1989-90	70,623	200	2nd wk. of June	6 April-28 July
1990-91	23,668	431	2nd wk. of May	27 March-1 July

Typically, riparian pumps are allowed to draw as much water from the river as is reasonably beneficial for the intended use as determined by the SWRCB. The SWRCB may prohibit all riparian pump operations on the Mokelumne River during dry water years when the TNF estimate is determined to be zero (L. Moeler, pers. comm. 1992).

The impact of these unscreened riparian pumps on salmon smolt and steelhead survival in the Mokelumne River has not been quantified. However, research on the impact of pump diversions on smolt survival along the Sacramento and San Joaquin rivers indicates that collectively these pumps may result in considerable mortality during the period when the

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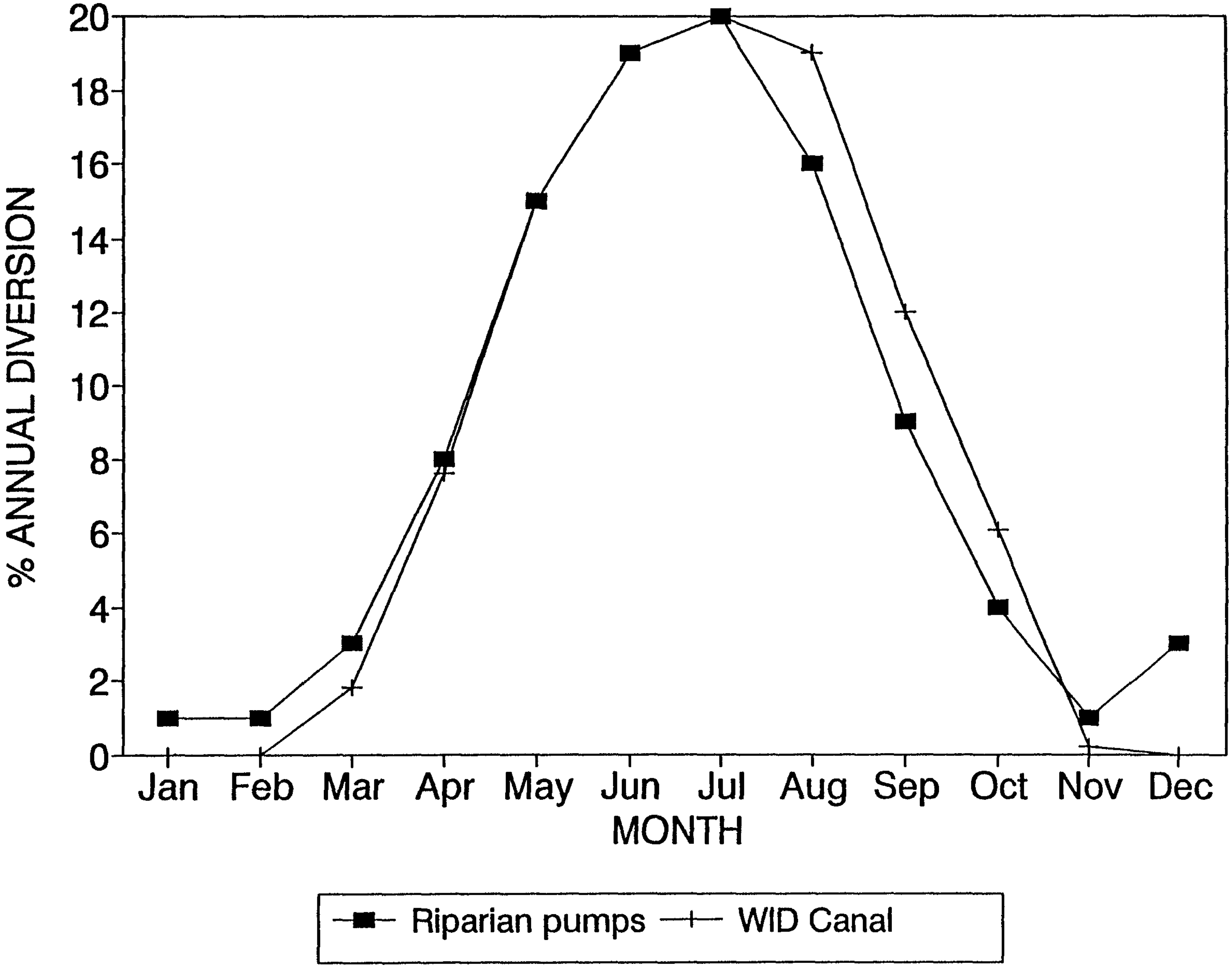

Figure 1-8. Percentage of annual flow by month for WID Canal and riparian pumps 1965 - 1988.

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Mokelumne River, peak diversions occur during salmon and steelhead rearing and salmon irrigation diversions and out-migration are concurrent (Hallock and Van Woert 1959). On out-migration, and intake pipes are often located along the river bank where juvenile salmon and steelhead are typically found.

Two major export pumping facilities and many smaller diversions in the central Delta impact Mokelumne River salmon fry and smolt heading out to sea through the San Joaquin River. One of the major pumping facilities is the Tracy Pumping Plant of the Central Valley Project (CVP), which was constructed in 1951 and can pump up to 4,600 cfs from the San Joaquin River (Gaines 1981). The other large facility is the Harvey O. Banks Delta Pumping Plant of the State Water Project (SWP), which began operations in 1967 and now has a capacity of 10,300 cfs (Department of Water Resources [DWR] 1990a).

Export pumps increase smolt mortality and reduce subsequent adult escapement for the Central Valley salmon stocks (Reisenbichler 1987). Smolt survival is reduced by increased predation, temperature stress, and handling stress at fish salvaging facilities (USFWS 1987). Even with modern fish salvaging techniques, CDFG research shows that a large number of fish encountering the export pumps are killed (Meyer 1982). Four coded wire tag (CWT) studies carried out in 1985 and 1986 showed that significant numbers of Mokelumne River salmon smolts were drawn to the export pumps (CDFG 1991).

The Delta Cross Channel was constructed in 1951 to divert water from the Sacramento River to the Delta export pumps via the Delta's north and south forks of the Mokelumne River. Diversions through the Delta Cross Channel are dependent on water year type, but usually range from about 0 cfs during the winter to over 4,500 cfs in the summer (DWR 1990b). These diversions substantially increase flow in the lower forks of the Mokelumne River. However, when the water reaches the confluence of the Mokelumne and San Joaquin rivers, much of the water is drawn up the San Joaquin River (reverse flow) by the export pumps. This flow pattern often draws salmon from their normal migration routes.

1.3.6 Mokelumne River Fish Hatchery

The MRFH was constructed in 1964 to mitigate for the loss of habitat for an estimated 10,000 adult salmon lost from construction and operation of Camanche Reservoir (Groh 1965). The facility was constructed by EBMUD pursuant to a 1961 agreement with CDFG. The mitigation agreement required EBMUD to construct a hatchery with the capacity for 100,000 yearling salmon or steelhead trout per year and an artificial spawning channel with the capacity for 15,000,000 salmon eggs per year. The facility was designed and is operated and maintained exclusively by CDFG.

In recent years (1984-1988), less than 800 adult salmon per year returned to the hatchery (Table 1.4). Current CDFG management goals call for returns of 10,000 adults to the fish facility and 5,000 adults to the river. CDFG has imported eggs from the American River and Feather River systems to augment poor adult returns on the Mokelumne River. EBMUD

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Table 1.4. Summary of the MRFH operations, including salmon and steelhead trout releases and returns. Based on the annual reports of the MRFH 1965-1989.

		NUMBER OF RELEASED*				
YEAR	ADULT RETURNS	FINGERLING	ADVANCED FINGERLING	YEARLINGS	TOTAL	RELEASE SITE**
Steelhead						
1964-65	45	163,280		92,525	255,805	MRFH
1965-66	30	131,420		84,410	215,830	MRFH
1966-67	17			82,203	82,203	MRFH
1967-68	103	125,760		101,207	22,696	MRFH
1968-69	24	125,760		101,207	226,967	MRFH
1969-70	134	137,695		122,822	260,517	Mokelumne
1970-71	215	152,862		107,972	260,834	MRFH
1971-72	14	82,180		111,926	194,106	MRFH
1972-73	11	38,864		154,344	193,208	MRFH
1973-74	18	286,590		48,285	334,875	MRFH
1974-75	2	46,400		77,985	124,385	MRFH
1975-76	***	14,600		57,202	71,802	MRFH
1976-77	***			51,752	51,752	MRFH
1977-78	***			8,237	8,237	MRFH
1978-79	***			10,559	10,559	MRFH
1979-80	***			56,170	56,170	MRFH
1980-81	***			54,649	54,649	MRFH
1981-82	***			51,530	51,530	MRFH
1982-83	***			43,493	43,493	MRFH
1983-84	***			48,132	48,132	MRFH
1984-85	***			53,716	53,716	MRFH
1985-86	***			53,200	53,200	MRFH
1986-87	48			56,215	56,215	MRFH
1987-88	0	351,600		173,554	525,154	Sacramento
1988-89	7	341,600		0	341,600	Sacramento
1989-90	11			170,000	170,000	MRFH
Salmon						
1964-65	242	73,450			73,450	MRFH
1965-66	173	76,435			76,435	MRFH
1966-67	293	76,796			76,796	MRFH
1967-68	250	177,542			177,542	MRFH
1968-69	565	37,866			37,866	MRFH
1969-70	296	497,130			497,130	MRFH
1970-71	377	564,670			564,670	MRFH
1971-72	366	560,506			560,506	MRFH
1972-73	353	40,417			40,417	MRFH
1973-74	408	176,216			176,216	MRFH
1974-75	220	7,216		54,948	62,164	MRFH

Table 1.4. Summary of the MRFH operations, including salmon and steelhead trout releases and returns (cont.).

YEAR	ADULT RETURNS	NUMBER OF RELEASED* FINGERLING	ADVANCED FINGERLING	YEARLINGS	TOTAL	RELEASE SITE**
1975-76	399	68,070		49,542	117,612	MRFH
1976-77	74	71,280		51,855	123,135	Rio Vista
1977-78	0		110,680	52,500	163,186	Rio Vista
1978-79	484			742,718	742,718	Rio Vista
1979-80	507	105,050	274,982	552,342	932,374	Rio Vista
1980-81	639	167,034	115,800	999,980	1,282,814	Rio Vista
1981-82	1,386			1,075,078	1,075,078	Rio Vista
1982-83	2,677	554,498		761,103	1,315,601	Rio Vista
1983-84	4,573	110,250		767,650	877,900	Rio Vista
1984-85	959		763,415		763,415	Maritime****
1985-86	223	262,985	392,314	1,131,700	1,786,999	Maritime****
1986-87	1,913	1,859,415	1,922,160	36,000	3,817,575	Benecia
1987-88	630	2,340,150	481,920		2,822,070	Berkeley
1988-89	128	2,474,800			2,474,800	Rodeo

* Salmon life-stage was determined by release date and may not agree with annual reports. Fingerling were released April-June, advanced fingerling were released July-September, and yearling were released after 1 October

** Release site is location of the majority of releases

*** The fish ladder at MRFH was only operated during the chinook salmon up-migration

**** "Maritime" refers to the Maritime Academy near Carquinez Strait

is currently funding a Hatchery Master Plan study to evaluate hatchery operations now and to make recommendations for future operations.

Prior to the construction of Camanche Dam, EBMUD built an experimental spawning channel at Lancha Plana that was operated by CDFG to determine the potential effectiveness of the proposed artificial spawning channels. The experiment showed that salmon would spawn in this artificial channel and that eggs could successfully be reared through out-migration, although there were problems with heavy metal toxicity (Menchen 1961). Construction on the MRFH began at the base of the Camanche Dam in 1963.

In 1964, CDFG began operating an artificial spawning channel for chinook salmon and rearing raceways for steelhead trout. The spawning facility consisted of a 2072 by 6 meter wide channel that formed two loops, each 1036 meters long. The channel provided 11,148 square meters of spawning habitat, which was estimated to provide enough habitat for 2,000 redds and a total spawning population of 4,700 fish (Groh 1965).

The original design for the hatchery was meant to replace the natural habitat lost above Camanche Dam with suitable spawning sites within a regulated environment (Menchen 1961; Groh 1965). Fry were to be released into the river during the natural out-migration period. In addition to the spawning channel, two raceways were constructed for steelhead rainbow trout. The small hatchery building and two raceways provided 100,000 steelhead rainbow trout yearlings. Originally, it was believed that stocking the river with fingerlings would establish a steelhead fishery on the Mokelumne River (Groh 1965).

By 1976, it became evident that attempts to establish a steelhead run on the Mokelumne River were unsuccessful. Although the CDFG continued to plant steelhead, none returned to the Mokelumne River hatchery during the 11 years between 1975 and 1985 (Table 1.4). During this time, the fish ladder into the hatchery was only operated during the salmon up-migration period (approximately October - December). Almost all of the steelhead planted returned to the American River (Meyer 1982). Because of these findings, the focus changed from planting fingerling and yearling steelhead to weekly plants of catchable steelhead during the recreation season (Meyer 1982).

Salmon production has increased considerably since the MRFH was built in 1964 (Table 1.4). During the first 8 years of operation, the salmon spawning stock at the hatchery was supplemented by trapping adults at Woodbridge Dam and transporting them to the hatchery. Only half of the spawning channel was used because of the low number of spawners. The second half of the channel was opened for the first time in 1970 when almost 1,300 fish arrived during the fall run.

Until 1973, salmon were reared from eggs to fingerling size and released directly into the river during the natural out-migration period. Since return rates during the first 10 years of operation were disappointing, CDFG began extending the rearing period to produce yearlings in 1973 (Jewett 1975). Gradually, salmon production methods shifted from a low maintenance spawning channel to a conventional hatching and rearing facility; however, standard facilities to effect this management change were not constructed.

In 1976, fingerlings were imported from other hatcheries to supplement salmon production at the facility and, since 1983, most fish raised in the MRFH have been obtained from other hatcheries (Jewett 1980). By 1979, salmon rearing at the MRFH had intensified and one of the spawning loops was converted into a series of rearing ponds with a maximum capacity of 1,000,000 yearling salmon (Jewett 1982).

CDFG has conducted research since the early 1970s to determine which smolt size and release site would maximize the return rate (Sholes and Hallock 1979; Meyer 1984). Two of the principal findings were that: 1) the rates of return to the ocean fishery and inland spawning stocks were higher for advanced fingerlings than fingerlings, and 2) overall survival increased greatly when fish were trucked and released in the Delta, as opposed to being released upstream at the hatchery. Transporting smolts across the Delta and releasing them into San Francisco Bay results in higher return rates because mortalities associated with downstream and Delta migration are avoided. However, smolts released in the Bay and lower Delta tend to stray to rivers other than the Mokelumne. Most return to the American, Feather, and upper Sacramento rivers. In comparison, a large proportion of yearlings released in the Mokelumne River return to the Mokelumne River (Table 1.5)

Table 1.5. Summary of experimental CWT releases of Mokelumne-reared salmon yearling, 1977-1979. Release sites were on the Mokelumne River at the MRFH and on the lower Sacramento River at Rio Vista (Meyer 1984).

	RELEASE SITE							
	MOKELUMNE RIVER				RIO VISTA			
	1977	1978	1979	TOTAL	1977	1978	1979	TOTAL
Number Released	44,287	38,739	42,504	125,530	44,234	36,610	39,137	119,981
Fishery Catch Estimate								
Commercial	407	775	178	1284	881	2295	446	3,622
Sport	102	70	47	219	279	245	121	645
Total	509	845	225	1,503	1,160	2,540	567	4,267
River Escapement								
Mokelumne River	28	112	23	163	4	9	4	17
American River	12	8	0	20	40	23	10	73
Other rivers	4	0	4	8	37	23	12	72
Total	44	120	27	191	81	55	26	162
Stray Rate (%)								
To American River	27	7	0	10	49	42	38	45
Total	36	7	1	15	95	84	85	90

Transporting smolts to Rio Vista on the Sacramento River or the Carquinez Strait estuary also increases survival, but this has the negative effect of greatly increasing straying. In dry years, under present operating procedures, the salmon produced in both the river and the MRFH are trucked across the Delta.

According to CDFG (Meyer 1984), planting fish from the MRFH into the Delta would contribute more to the ocean fishery than planting fish in the Mokelumne River. Although planting fish in the Delta increases the salmon fishery, fewer salmon return to the Central Valley, and only a small percentage return to the Mokelumne River. Table 1.5 summarizes a 3-year CWT study of salmon releases from the MRFH. Only 10 percent of returning Mokelumne River fish planted in the Delta return to the Mokelumne River; 90 percent stray to other rivers. Conversely, 85 percent of Mokelumne River releases return to the Mokelumne River. This clearly suggests that to achieve better return rates to the Mokelumne River, salmon should be released in the Mokelumne River when conditions are optimal for survival.

By the early 1980s, it appeared that improved rearing techniques and hatchery operations were a success because hatchery returns and overall stock estimates increased dramatically (Figure 1-9, Table 1.6). Over 4,500 adults returned to the MRFH in the 1983-1984 season and, between 1982 and 1985, stock estimates were higher than at any time in the prior 25 years (Table 1.6). Because of this success, CDFG decided to rear fish to the size of advanced fingerlings instead of yearlings to lower costs while maintaining high survival (Meyer 1988). Most fish released from the hatchery since 1984 have been advanced fingerlings (Estey 1990).

Over the 50-year history of recorded salmon stock estimates on the Mokelumne River, the salmon population in the river has experienced wide fluctuations. Recent success at the hatchery lasted as long as water was abundant. With the current drought that began in 1987, hatchery returns have decreased to low levels. Low Mokelumne River Watershed Basin runoff has led to low Camanche Reservoir levels. This resulted in high phytoplankton populations, low dissolved oxygen concentrations, and increased water temperatures, turbidity, and hydrogen sulfide during the summer and fall in water released from Camanche Reservoir (Miyamoto 1990). In September 1987, low water levels in Camanche Reservoir resulted in substantially decreased dissolved oxygen levels and increased temperature, turbidity, and hydrogen sulfide. These conditions resulted in the loss of 150,000 steelhead fingerlings at the hatchery (Horne 1989).

In 1988, poor water quality resulted in the loss of 144,000 steelhead, and salmon were released at a smaller size to avoid further losses at the hatchery (Estey 1989). In 1990, aeration of the MRFH inflow did not sufficiently eliminate the anoxic conditions during the late summer, and the hatchery water was treated with potassium permanganate to eliminate hydrogen sulfide (Miyamoto 1990). In 1990 and 1991, fish losses from high water temperatures and low dissolved oxygen levels were avoided by chemical treatment, supplemental MRFH aeration, increased releases from Pardee Reservoir, and selective withdrawal from Camanche Reservoir to supply water to the MRFH.

1.3.7 Introduction of Exotic Species

Introduced or exotic species are gradually replacing native species in the rivers of the Central Valley. Many studies have documented the way in which exotic species rapidly invade habitat and usurp available niches, thereby displacing native species (Kornberg and Williamson 1986; Moyle 1976; Usher 1988). In general, introduced fish have a greater impact on native species when habitats have been drastically altered by man (Moyle 1976). Much of the loss of native fauna in the Central Valley can be attributed to the construction of dams (Moyle and Nichols 1973).

Surveys reveal that there are more introduced fish species than native ones in the Mokelumne River (Table 1.7). Nine native species have been documented in the Mokelumne River in recent years, and four more could potentially be found. At the same time, 19 introduced species have been verified. Electrofishing and seining surveys in 1990-1992 found bluegill, smallmouth bass, spotted bass, redear sunfish, golden shiner, and mosquitofish. Sacramento

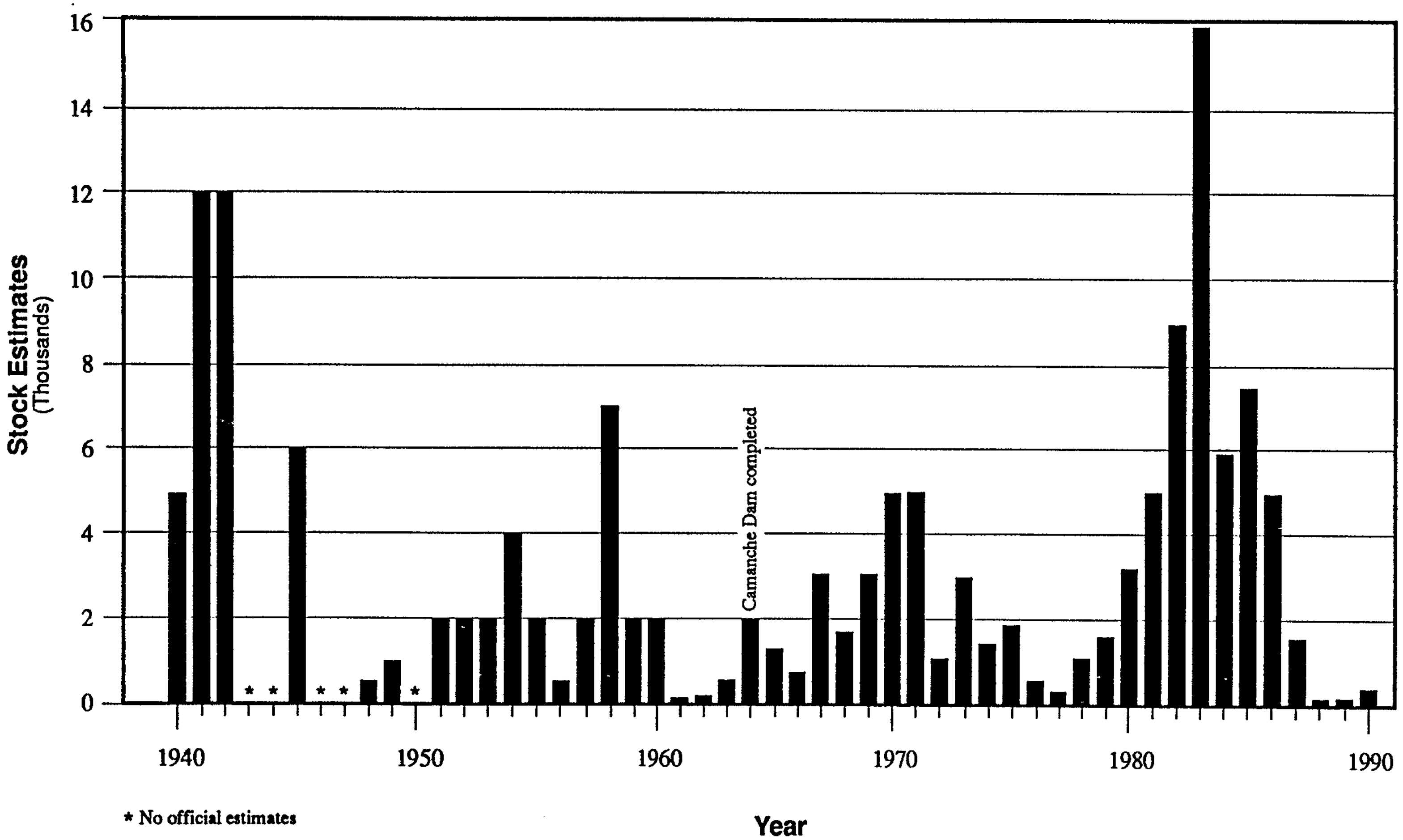

Figure 1-9. Mokelumne River salmon stock estimates, 1940-1990.

BioSystems

Table 1.6. Summary of Mokelumne River salmon stock estimates, including river estimates and hatchery arrivals.

YEAR	STOCK ESTIMATE	RIVER ESTIMATE	HATCHERY* ARRIVALS	DATES OF RUN**
1940	5,000	4,986	--	thru 11/04
1941	12,000	11,572	--	thru 11/25
1942	12,000	10,019	--	thru 11/19
1943	NA	--	--	--
1944	NA	--	--	--
1945	6,000	--	--	--
1946	NA	--	--	--
1947	NA	--	--	--
1948	500	230	--	--
1949	1,000	765	--	10/26-12/27
1950	NA	--	--	--
1951	2,000	1,642	--	10/10-12/24
1952	2,000	1,878	--	10/07-12/13
1953	2,000	2,439	--	10/01-12/16
1954	4,000	3,939	--	10/12-12/13
1955	2,000	2,193	--	11/15-12/21
1956	500	474	--	10/07-12/18
1957	2,000	2,403	--	10/05-12/26
1958	7,000	6,926	--	10/03-01/07
1959	2,000	2,108	--	10/07-01/12
1960	2,000	2,208	--	10/05-12/28
1961	100	137	--	10/19-12/18
1962	200	230	--	09/29-12/19
1963	500	481	--	10/03-12/16
1964	2,000	2,210	242	10/07-12/16
1965	1,300	NA	173	NA
1966	700	689	293	10/03-12/16
1967	3,000	1,989	250	10/03-12/29
1968	1,700	1,657	565	10/15-12/17
1969	3,000	2,085	296	10/23-12/07
1970	5,000	3,516	377	10/20-12/23
1971	5,000	5,091	366	09/27-12/13
1972	1,100	750	353	10/11-01/22
1973	3,000	2,193	408	10/10-01/29
1974	1,400	1,200	220	10/06-01/05
1975	1,900	1,501	399	10/07-01/09
1976	500	465	74	11/16-12/30
1977	300	250	0	NA
1978	1,100	600	484	10/02-12/16
1979	1,500	1,000	507	10/16-11/24
1980	3,200	2,592	639	10/10-12/15
1981	5,000	4,454	1,386	10/13-12/18
1982	9,000	6,695	2,677	10/06-12/22
1983	15,900	11,293	4,573	10/06-12/14
1984	5,969	NA	959	10/06-12/07
1985	7,702	7,459	223	11/04-12/21
1986	5,000	4,450	1,913	10/15-01/09
1987	1,650	276	630	10/22-12/24
1988	528	NA	128	10/24-02/16
1989	280	NA	90	NA
1990	431	NA	64	10/16-12/17

* Does not include fish trucked to MRFH from Woodbridge Dam.

** Dates for 1940-1971 are the dates of Woodbridge counts. After 1971, the dates are inclusive for hatchery arrivals.

Table 1.7. Native and introduced fishes potentially inhabiting the Lower Mokelumne River. Species' distributions are based on field research (confirmed) and general species descriptions (confirmed and potential) (Moyle 1976; Moyle et al. 1989).

COMMON NAME	SCIENTIFIC NAME	DISTRIBUTION[1]
NATIVE - CONFIRMED[2]		
Pacific lamprey	*Lampetra tridentata*	CAM, WB
Chinook salmon	*Oncorhynchus tshawytscha*	CAM, WB
Steelhead rainbow trout	*Oncorhynchus mykiss*	CAM, WB
California roach	*Hesperoleucus symmetricus*	CAM, WB
Hitch	*Lavinia exilicauda*	CAM, WB
Sacramento squawfish	*Ptychocheilus grandis*	CAM, WB
Sacramento sucker	*Catostomus occidentalis*	CAM, WB
Tule perch	*Hysterocarpus traski*	CAM, WB
Prickly sculpin	*Cottus asper*	CAM, WB
NATIVE - POTENTIAL[3]		
White sturgeon	*Acipenser transmontanus*	WB
Sacramento blackfish	*Orthodon microlepidotus*	WB
Hardhead	*Mylopharodon conocephalus*	CAM, WB
Sacramento splittail	*Pogonichthys macrolepidotus*	WB
INTRODUCED - CONFIRMED[4]		
Threadfin shad	*Dorosoma petenense*	CAM, WB
Common carp	*Carassius carpio*	CAM, WB
Goldfish	*Carassius auratus*	CAM, WB
Golden shiner	*Notemigonus crysoleuces*	CAM, WB
Channel catfish	*Ictalurus punctatus*	CAM, WB
White catfish	*Ictalurus catus*	CAM, WB
Black bullhead	*Ictalurus melas*	CAM, WB
Brown bullhead	*Ictalurus nebulosus*	CAM, WB
White crappie	*Pomoxis annularis*	CAM, WB
Black crappie	*Pomoxis nigromaculatus*	CAM, WB
Green sunfish	*Lepomis cyanellus*	CAM, WB
Bluegill	*Lepomis macrochirus*	CAM, WB
Redear sunfish	*Lepomis microlophus*	CAM, WB
Pumpkinseed	*Lepomis gibbosus*	CAM, WB
Smallmouth bass	*Micropterus dolomieui*	CAM, WB
Largemouth bass	*Micropterus salmoides*	CAM, WB
Spotted bass	*Micropterus punctulatus*	CAM, WB
Redeye bass	*Micropterus coosae*	CAM, WB
Mosquitofish	*Gambusia affinis*	CAM, WB
INTRODUCED - POTENTIAL[3]		
Striped bass	*Morone saxatilis*	WB
American shad	*Alosa sapidissima*	WB
Bigscale logperch	*Percina macrolepida*	CAM, WB

[1] The distribution of fish species in the Lower Mokelumne River is divided into two river sections: Camanche Dam to Woodbridge Dam (CAM), and Woodbridge Dam to the extent of tidal influence (WB).
[2] Confirmed species are based on field observations and surveys by BioSystems, EBMUD, and the CDFG.
[3] Potential species inhabiting the Lower Mokelumne River are based on general species descriptions (Moyle 1976; Moyle et al. 1989).
[4] CDFG (1991) documented one striped bass in the Lower Mokelumne River. The site of capture is not specified, but it is believed to be at the extent of tidal influence based on historical species distribution and survey sampling design outlined by CDFG (1991).

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sucker and prickly sculpin were abundant native species. In a separate study, CDFG (1991) found an abundance of prickly sculpin.

The effects of exotic fishes fall into two categories: ecosystem alteration and the elimination of native fish populations (Moyle 1976). Exotic fish can alter ecosystems by removing aquatic vegetation and degrading water quality and reduce native fish populations directly through competition, predation, and hybridization. However, alteration of habitat by introduced fish has not been found to be a major problem in the Mokelumne River.

The effects of introduced species on native fish has not been documented in the Mokelumne River, but similar species have been studied in other rivers in California (Moyle and Nichols 1973). Bluegill have replaced native Sacramento perch in many river systems where they were once plentiful, such as in the Sacramento and San Joaquin rivers (Moyle 1976). Sacramento perch are ecologically similar to bluegill, but, since they are less aggressive, they can be driven from cover, food supplies, and breeding sites (Moyle and Nichols 1974).

Introduction of largemouth or smallmouth bass may reduce or eliminate native fishes through predation (Minckley 1973). Introduced black bass are at the top of the aquatic food chain and feed on native and introduced fish, depending on availability (Moyle 1976). Another introduced species, the green sunfish, is abundant in the Mokelumne River and out-competes the native California roach for food and habitat. When green sunfish and California roach are trapped together in isolated pools, green sunfish usually eliminate the native roach.